iC-MU Magnetic Encoder
Calibration and Programming
1. **Tools & Documentation for Calibration and Programming**

1. iC-MU Website ([www.ichaus.com/mu](http://www.ichaus.com/mu))
3. iC-MU Datasheet ([www.ichaus.com/mu_datasheet_en](http://www.ichaus.com/mu_datasheet_en))
4. iC-MU MU1D Demo Board ([www.ichaus.com/MU1D_evalmanual_en](http://www.ichaus.com/MU1D_evalmanual_en))
5. iC-MU MU1M Demo Board ([www.ichaus.com/MU1M_evalmanual_en](http://www.ichaus.com/MU1M_evalmanual_en))
6. iC-MU Magnet (MU2S, MU27S, MU18S, or equivalent) ([www.ichaus.com/mu](http://www.ichaus.com/mu))
7. Mechanical mounting test setup
8. iC-Haus iC-MU GUI
   a. with included LabVIEW RTE ([www.ichaus.com/MU_gui_rte](http://www.ichaus.com/MU_gui_rte))
   b. without LabVIEW RTE ([www.ichaus.com/MU_gui](http://www.ichaus.com/MU_gui))

For iC-MU150 documentation and tools please check respective iC-MU150 product website.

2. **Mechanical Tolerances**

Understanding the allowable mechanical tolerances of an iC-MU based system is required for a successful calibration and reliable product implementation.

![Figure 1 - Definition of radial, tangential, and eccentricity tolerances](image-url)
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<td>Permissible Eccentricity of Code Disc</td>
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*Table 1 - Permissible mechanical alignment tolerances*

Please refer to iC-MU magnetic target specifications (MU2S, MU27S, MU18S, or equivalent) for positioning information of iC-MU relative to the magnetic target.
3. Setup

1. Mount the iC-MU magnet and MU1M module per the above mechanical specifications.
2. Connect the ribbon cable from the MU1M to the MU1D board connector J1.
3. Connect the MB3U-I2C adapter 9 pin Sub D connector to the MU1D board connector J2.
4. Connect the MB3U-I2C adapter ribbon cable to the MU1D board connector J3.
5. Ensure that Jumpers JP1, JP5 & JP6 are closed. It is recommended to power the MU1D board through an external stabilized and filtered power supply for calibration. Ensure that JP2 and JP3 are open in that case. If no external power supply is available the board can be powered through J2 using the MB3U-I2C adapter. In this case ensure that JP2 is closed.

**Note:**
It is not recommended to power the board through the SPI port J3 from the interface adapter MB3U-I2C (JP3 closed).

*Figure 4 - Example iC-MU test setup allowing X, Y, and Z adjustments*
6. Launch the iC-MU PC GUI. (Always ensure that you use the latest SW version. It can be found on www.ichaus.com/software)

7. Press the <Disconnected> button and verify the status changes to <Connected>.

8. When using the MB3U-I2C adapter calibration can only be carried out properly in SPI mode. Please verify that <Port A Configuration> under tab <Interface> is set to <SPI>. If not please select <SPI>. The MB3U-I2C adapter will automatically switch to SPI in this case. As confirmation <MB3U-SPI> is also displayed next to the <Connected> button.

When using the MB4U or MB5U adapter the calibration needs to be carried out in BiSS mode.

9. Under the Analog tab, enable Amplitude Control.
10. Under the <Nonius/Multiturn> tab, select the following:
   a. Under Hall Sensor Arrangement, select <Rotative> for use with MU2S and MU18S axial magnets or <Linear> for use with MU27S radial magnet or linear magnetic tapes.
   b. Under Master Period Count, select <32> for use with the MU2S, MU27S, MU18S, or other qualified 32/31 pole pair iC-MU magnetic targets.
   c. Under <Filter Features>, select 39dB = 0x04. This is the optimal setting for conducting the analog calibration procedure. Higher filter settings (e.g. 45dB or 51dB) are permissible, but might significantly prolong the duration of the analog calibration procedure. More calibration iterations might be needed in Step 15.

11. Under tab <CalibSetup> select <Automatic> and <Singleturn Calibration> for Rotary applications that rotate continuously. Set to <Manual> and <Singleturn Calibration> for Linear applications or rotary applications that can only rotate less than 360° or do not rotate continuously. For Calibration Reference, select <Variable Velocity>. The setting <Constant Velocity> should only be used if calibration is carried out in BiSS mode with an MB4U or MB5U adapter and the magnet is rotating at a very constant speed.
4. Calibration

12. Rotate iC-MU magnet target at a constant speed.

Under tab <CalibSetup> the calibration parameters can be adjusted.

**<Cycle Count>:** The number of samples used for the calibration algorithm. **At least one full rotation of the magnetic target needs to be sampled!**

**<SPI Frequency>:** The rate at which the measurement values are read back from the encoder for SPI calibration (no effect on BiSS calibration).

**<Frame Repetition Rate>:** The rate at which the measurement values are read back from the encoder for BiSS calibration (no effect on SPI calibration).

**<BiSS Frequency>:** Leave at default 2 MHz.

**SPI calibration:** For rotation speeds in between 50 – 350 RPM a <SPI Frequency> of 100 kHz and a <Cycle Count> of 5,000 should yield good results.

**BiSS calibration** (only with adapter MB4U or MB5U): The GUI default <Frame Repetition Rate> setting of 187.5 µs and a <Cycle Count> of 10,000 should yield good results for rotation speeds in between 50 – 350 RPM. For rotation speeds of 350-800 RPM <Frame Repetition Rate> should be set to about 70-100 µs.
It is not recommended to calibrate outside of the rotational speed ranges mentioned above. Nevertheless if you chose to do so, it might be necessary to experiment with the <SPI Frequency>, <Frame Repetition Rate> and <Cycle Count> settings. Please also refer to the formulas in the annex.

**Higher rotational speeds:**

SPI Calibration: Increase SPI Frequency  
BiSS Calibration: Lower Frame Repetition Rate

**Lower rotational speeds:**

SPI Calibration: Lower SPI Frequency  
BiSS Calibration: Increase Frame Repetition Rate

*Note:*  
It is recommended to verify the quality of the calibration with suitable external tools.

13. Under the Analog tab, press <Set default Values> to first reset the signal conditioning values to their default values.

![Automatic Analog Calibration interface](image)

Relative changes in LSB | Master | Nonius
--- | --- | ---
Cosine Gain | 0 | 0
Sine Offset | 0 | -1
Cosine Offset | 0 | 1
Phase Adjust | 0 | 0

*Figure 12 - iC-MU GUI, Starting the analog calibration*
15. Analog calibration is performed and the progress displayed in a status bar. As the analog calibration is an iterative process it can be repeated to achieve better results. The values in the fields <Cosine Gain>, <Sine Offset>, <Cosine Offset> and <Phase Adjust> of the area “Relative changes in LSB” should be as close to zero as possible. A tolerance of +/- 3 is considered as good. Usually this is achieved after max. 3 iterations.

![Figure 13 - iC-MU GUI, Analog Calibration - Relative changes in LSB](image)

16. Review the Analog calibration result. The better the mechanical alignment of the iC-MU relative to the magnetic target the closer the Sine and Cosine Offset values and Phase Adjust values will be to zero. Acceptable mechanical alignment should at least yield the following results:
   a. All Sine and Cosine Offset values are within +/- 10 mV.
   b. Both Phase Adjust values are within +/- 2°.

**Note:**
The Offset and Phase adjust limits above should be seen as recommendation only. The internal circuitry can compensate for even larger errors. As long as the control limits are not reached the system might still yield acceptable overall performance with a less accurate mechanical alignment. This needs to be evaluated and verified in the final application on a case to case basis.

Nevertheless it is always advisable to mechanically adjust the system as accurately as possible in the respective application.

Please keep in mind that unsatisfactory calibration results can also be caused by poor or defective magnetic targets.
17. If both Sine and Cosine Offsets are out of tolerance (example shown below), check the air gap distance from the iC-MU package to the magnet target surface (0.4 mm). After adjustment redo the analog calibration starting with Step 13.

Potential for optimization of mechanical alignment
18. If the Phase Adjust is out of tolerance (example shown below) adjust the mechanical position (X, Y, or both) of the iC-MU and redo the Analog calibration starting with Step 13.

Potential for optimization of mechanical alignment
19. After a successful Analog calibration has been achieved, and with the iC-MU magnet still rotating at a constant speed adjust the Filter Setting (refer to Step 10) to the value that will be used in the final application. Then press <Calibrate> from under the Nonius Calibration tab.

20. Calibration is complete once the status bar finishes.
21. Three curves will be shown:

**Red curve (Error):** This is the uncorrected nonius error curve

**Blue curve (SPO):** This is the calculated correction curve

**Green curve (Result):** This is the corrected nonius curve. A successful Nonius Calibration will be shown by the resulting green curve (example shown below) being well within the upper and lower bound limits as shown by the turquoise lines. Keeping the limits below +/- 150 counts is recommended.

![Figure 20 - iC-MU GUI, Good nonius calibration result](image)

22. If the Nonius Calibration is out of tolerance (example shown below) adjust the mechanical position (X, Y, or both) of the iC-MU to the magnet, verify the air gap of the iC-MU package to the magnet surface, and redo the Analog and Nonius Calibration starting with Step 13.

![Figure 21 - iC-MU GUI, Bad nonius calibration result](image)
23. After a successful Nonius calibration has been achieved, and with the iC-MU magnet still rotating at a constant speed, select the <Error/Warning/Status> tab and perform the following:

   a. Check mark the <Accumulated> box.
      Now the status flags will be hold until you read the status register in case an error occurred only once.
   b. Enable the <Show Details> check box. This will bring up the Status Information Window.

![Figure 22 - iC-MU GUI, <Error/Warning/Status> tab settings](image-url)
c. Click the <Read Status> button in the Status Information Window after at least one full rotation has completed (highlighted below). No Error should be present.

![Status Information Window](image)

**Figure 23 - iC-MU GUI, Status Information Window with no errors**

**Note:**
If the Period counter consistency error (NON_CTR) is red, the iC-MU system cannot calculate the correct absolute position value. In this case the system will not work properly.
24. If any indicators are red verify the mechanical alignment and air gap of the iC-MU package to the magnet surface and redo both the Analog and Nonius Calibration starting with Step 13.

![Status Information Window with errors](image-url)

*Figure 24 - iC-MU GUI, Status Information Window with errors*
25. If there are persistent errors with the Analog Calibration, Nonius Calibration, or the Error/Warning/Status, one method to aid in real-time debugging is to utilize the Continuous Measure function in the Nonius Calibration tab:
   a. Rotate the iC-MU magnet at a continuous speed.
   b. Check mark the Continuous Enable box in the Nonius Calibration tab.
   c. Press <Measure> in the Nonius Calibration tab.
   d. Adjust the mechanical alignment of the iC-MU package to the magnet surface and optimize for the best Nonius Curve in green.
   e. Once the alignment has been optimized, redo the Analog and Nonius Calibration starting with Step 13.

26. After the Analog Calibration, Nonius Calibration, and Error/Warning/Status are all in tolerance and successful, the calibration is complete and ready to be programmed into the connected EEPROM:
   a. Press <Write EEPROM> at the bottom of the GUI screen.

27. Calibration Complete
5. Linear Calibration

For linear measurement applications like shown below the calibration procedure is slightly different.

A. Ensure that you chose the linear settings in Step 10 & 11. Under tab <Analog> the additional option <Start immediately> is available. Leave it unchecked for now and hit the <Calibrate> button.
The calibration wizard window will appear.

![Figure 30 - iC-MU GUI, Calibration Wizard for linear calibration](image)

<Start Delay> determines the delay in between hitting the <Go> button and start of the calibration measurement. It can be set in between 0 to 10 s. If <Start Immediately> in the <Analog> tab is enabled both Step 1 and Step 2 of the calibration measurement will start automatically after the start delay expires without any further user interaction. This option can be used to speed up the calibration procedure.

In general the start delay is useful when the target / iC-MU is moved manually or machine movement has to be triggered manually.

B. Depending on what interface is used for calibration configure the <SPI Frequency>, <Frame Repetition Rate> and Cycle Count.

To determine suitable settings consider the following:

- Only the distance that will be used later on in the application needs to be measured for calibration.
- Determine how long it takes to pass this distance.
- Match the measurement time to the time it takes to pass the measurement distance. This can be done by adjusting parameters <SPI Frequency>, <Frame Repetition Rate> and <Cycle Count>. Please refer to the formulas in the annex.
SPI Calibration:
For manual movement a <SPI Frequency> of in between 25-100 kHz usually yields good results. The slower the movement the lower the frequency should be.

BiSS Calibration:
For manual movement a <Frame Repetition Rate> of in between 187.5-500 µs usually yields good results. The slower the movement the higher the repetition rate should be.

C. Hit the <Go> button (not necessary if <Start Immediately> is selected). After the start delay expires analog calibration data acquisition will start with Step 1. For analog calibration it is important that the target / iC-MU is moved as uniformly as possible over the whole measurement duration. Please avoid:

- Standstill of target / iC-MU during the measurement
- Larger Accelerations or decelerations of target / iC-MU during the measurement
- Change of movement direction during the measurement

It is advisable to start the movement slightly before the data acquisition starts and to end the movement slightly after data acquisition finished (please see Figure 31 below).

![Figure 31 - Analog calibration linear movement recommendation](image-url)
Active data acquisition is indicated by the “Processing… please wait” message window.

After successful calibration Step 1 will display the message “Good! Complete range measured” and the indicator will light up green. If your measurement distance is shorter than a full nonius cycle the indicator will be yellow and the message “OK! Sub-range measured (> 4 periods) will be displayed. As described above this is OK as only the measurement distance that will be used later on in the application has to be calibrated.

D. In Step 2 the calibration is verified and correction factors are determined. Movement is to be carried out in the same way as for Step 1. It will finish with the same messages as in Step 1.

An error message will be displayed if the calibration or measurement fails. In this case the calibration procedure is aborted and needs to be repeated. This could be for example due to too slow or fast movement or an insufficient measurement distance.
E. If the analog calibration finished successfully the calibration wizard window will look as in Figure 33. Hit “Ok”. The next steps of the analog calibration can be carried out analog to steps 15 – 18 of the rotary calibration procedure.

F. Once the analog calibration has been finished the nonius calibration needs to be carried out. Please ensure that you set the <Filter Feature> (refer to Step 10) to the value that will be used in the final application. For the nonius calibration the same calibration wizard is available as for the analog calibration. The procedure is the same as for step C & D except for that movement should start slightly after the data acquisition is running and stop slightly before the data acquisition stops (please see Figure 34 below).
G. Once nonius calibration has been finished it is advisable to verify that the number of measured periods matches the measurement distance that needs to be covered in the application.

Example: With iC-MU a full period is 2.56mm long. If your measurement distance is 48 mm it equals 48 mm / 2.56 mm = 18.75 periods. The calibration wizard cuts the decimal places and should display 18 periods in that case (see Figure 35).

Figure 35 - iC-MU GUI, Linear nonius calibration finished

H. The calibration results will be shown after hitting OK. The results are displayed in the same way as in step 21. A difference to the rotary nonius calibration is that the curves might not be complete if the measurement distance is shorter than a full nonius cycle (see Figure 36). This is perfectly normal in this case.

Figure 36 - iC-MU GUI, Good linear nonius calibration result
I. As a last step the system should be checked for errors as in step 23 and following of the rotary calibration. Move the iC-MU or magnetic target over the measurement distance several times and follow the respective steps of the rotary calibration.
6. Rotary Calibration Procedure Flowchart

Conduct Setup Procedure (Step 1-11)

Spin magnetic target in valid RPM range (Step 12)

Tab: Analog <Set Default Values> (Step 13)

Tab: Analog <Calibrate> (Step 14)

Relative changes in LSB within +/- 3 (Step 15)

Yes

Review Analog Calibration Results - Offset (Step 16)

Offset within Limits?

No Adjust air gap (Step 17)

Yes

Review Analog Calibration Results - Phase (Step 16)

Phase within Limits?

No Adjust X, Y or both (Step 18)

Yes

Perform Nonius Calibration (Step 19-22)

Nonius within Limits?

No Adjust air gap (Step 17) Adjust X, Y or both (Step 18) Check magnetic target

Yes

Check for System Errors (Step 23-24)

Errors Present?

Yes

Save Configuration (Step 26)

Calibration Complete

Note:
The given offset and phase adjust limits should be seen as recommendation only. The internal circuitry can compensate for even larger errors. As long as the control limits are not reached the system might still yield acceptable overall performance with a less accurate mechanical alignment. This needs to be evaluated and verified in the final application on a case to case basis.

Nevertheless it is always advisable to mechanically adjust the system as accurately as possible in the respective application.

Please keep in mind that unsatisfactory calibration results can also be caused by poor or defective magnetic targets.
7. Annex

SPI Calibration

\[ \text{Measurement Duration [\mu s]} = \text{Cycle Count} \times \left( \frac{32}{\text{SPI Frequency [Hz]}} + 32.5 \mu s \right) \]

BiSS Calibration

\[ \text{Measurement Duration [\mu s]} = \text{Cycle Count} \times \text{Frame Repetition Rate [\mu s]} \]
8. Revision History

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<td>B1</td>
<td>Document revised, linear calibration guide added</td>
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<td>B2</td>
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